

Wind loading on buildings

Brief guidance for using BS 6399-2:1997

Digest 436

Part 1

Since BS 6399-2:1997 was published, some users have felt that guidance was needed to apply the Standard correctly. Queries raised by engineers also suggested that some background information might prove useful. This is the first of a three-Part Digest, using a question-and-answer format with the guidance arranged, as far as possible, in the same order as the Standard. Parts 2 and 3 provide worked examples of the BS 6399-2 method that illustrate the guidance and recommendations in this Part.

BS 6399-2 is less prescriptive than the previous Code, CP3:Chapter V:Part 2:1972, requiring the user to exercise judgement. The Code required up to four orthogonal load cases to be considered as standard using the worst wind speed, irrespective of direction, but allowing, from 1986, the option of using direction factors (S_d). The BS 6399-2 'standard method' gives the same choices but takes the choice of direction factors as standard and offers the worst wind speed, irrespective of direction, as a conservative option. BS 6399-2 offers an additional choice of the 'directional method', giving 12 wind

speeds in 30° sectors of wind direction; but this is more suitable for implementing by computer than manually. BS 6399-2 also offers some hybrid options that lie in-between standard and directional methods, being particularly useful for sites in towns.

The guidance in this Part will help the user to select the choices in BS 6399-2 that are equivalent to previous practice. It will also assist the user to eliminate conservatism in the standard method by considering wind direction, even when the orientation of a building is unknown, as shown in Table A.

This Digest is aimed at architects, engineers and professionals who need to know the effect of wind on buildings, and design options that minimise it.

The full title of BS 6399-2:1997 is *Loading for buildings: Code of practice for wind loads*. In this Digest we refer to it as BS 6399-2 or the 'Standard'. It supersedes BS 6399-2:1995 which itself was a technical revision of *Loading: Wind loads*, CP3:Chapter V:Part 3:1972 (abbreviated here to CP3-V-2 or the 'Code'); references to 'Code' are to this 1972 document.

Table A Wind speed options for standard method load cases

Option	Wind speed method	Orientation unknown	Orientation known
<div> <div> <div>↑</div> <div>Increasing complexity</div> <div>→</div> </div> <div> <div>←</div> <div>Increasing conservatism</div> <div>↓</div> </div> </div>			
1 Single worst case irrespective of direction	Standard method with $S_d = 1.0$	Gives the most onerous possible wind speed (CP3 'standard')	Gives the most onerous possible wind speed (CP3 'standard')
2 Four 90°-wide sectors	Standard method	Not applicable but wind speed in Option 1 could be used	Gives wind speed for each orthogonal case
3 Twelve 30°-wide sectors	Directional method	Gives the worst wind speed in any direction	Gives worst wind speed for each orthogonal case (CP3 using S_d)

Figures and tables in this Digest are denoted by letters (eg Figure A, Table A) to distinguish them from those in BS 6399-2. Except where specifically noted, any numbered reference to a Clause (§), Figure or Table, refers to that in BS 6399-2: 1997.

Q1: How does the scope of BS 6399-2 differ from CP3-V-2?

- The scope remains unchanged from CP3-V-2. Both predict the maximum gust load on a building, part or component that should be used in static design. This is called the ‘equivalent static gust method’.
- Both CP3-V-2 and BS 6399-2 are ‘head codes’, which means that other Codes and Standards refer to them for information. Examples of dependent Standards are the Code for slating and tiling, BS 5534; for farm buildings, BS 5502; and for glazing, BS 6262.
- Both CP3-V-2 and BS 6399-2 exclude dynamic structures. A new structural classification method has been introduced as a signpost to indicate when it is safe to proceed with BS 6399-2. This procedure extends the scope of BS 6399-2 to include mildly dynamic buildings without the need to adopt more complicated dynamic methods.
- Because most forms of industrial structure now have their own Code, for example lattice towers (BS 8100), hyperbolic cooling towers (BS 4485-4) and steel chimney stacks (BS 4076), the scope of BS 6399-2 now only covers buildings. Other structures were excluded from CP3-V-2 also by the 1986 amendments.

Q2: How has the structure of the Standard changed?

- The format and order of BS 6399-2 is dictated by the provisions of BS 0, ‘A standard for standards’. This requires the reason for each stage to be presented before the method to implement it. As a result, the order of the Standard is not the most convenient for design. The most convenient order of calculation is given by the flow chart, Figure 1. This uses the same order as given in CP3-V-2.
- All essential information from the CP3-V-2 appendices has been moved into the main clauses of BS 6399-2. This ensures compliance with all essential rules and reduces the possibility of misapplication.
- There is now a choice of ‘standard method’ and ‘directional method’ (see Q16). The standard method is as similar as practicable to the method of CP3-V-2.
- Hybrid combinations of wind speed and pressure coefficients of the standard and directional methods are possible (see §3.4). Using Equations 28 and 29 of the directional method to obtain the terrain-and-building factor, S_b , can reduce conservatism in the standard method, particularly in towns and near east or north-facing coasts.

Q3: What is the point of the ‘dynamic’ classification in §1.6?

- The dynamic classification is used to determine if the building lies within the scope of the Standard. Previously, CP3-V-2 excluded buildings ‘susceptible to dynamic excitation’ without providing any method to identify them.
- The method sets a value to the dynamic augmentation factor, C_r , that allows mildly dynamic buildings to be included, effectively extending the scope.

Q4: How does the dynamic classification work?

- The simplified implementation used in §1.6 assesses the horizontal motion of typical tall buildings and is generally conservative. It represents the natural frequency and wind excitation by the building height, H , and the building’s ability to damp out vibrations by the building type factor, K_b .
- It is possible for the method to underestimate the response of buildings that are not typical; for example, buildings that are strongly asymmetrical and that may respond in torsion. If there is reason to suspect non-typical characteristics, the lowest natural frequency of the building should be determined and the ‘full method’ equation, Equation C.3 of Appendix C, can be applied.
- While the dynamic assessment method does not cover cantilever roofs (eg stadia), an approximation is to take the cantilever span as the building height, H , in the full method equation, Equation C.3, together with building type factor $K_b = 2$.

Q5: What do I do if my building does not match the types given in Table 1?

- Table 1 gives all the reliable data that are currently available for building type factor, K_b . If your building does not correspond exactly to the building type descriptions in this Table, it is necessary to ask yourself the question ‘How will my building respond to dynamic loads in comparison with the descriptions given?’ Rank your building against the given descriptions, interpolating between descriptions and the lines in Figure 3 if necessary. When in doubt, take the next more onerous value of K_b in the Table.

Q6: The dynamic amplification factor, C_r , appears only in Equation 7 for overall loads. What do I do for cladding panels?

- The dynamic classification assesses only the overall response of the building to lateral loads, so C_r applies only to the design of the main structural members that resist the overall loads.
- Apart from the main structural members, all other components of the building (ie rafters, purlins, cladding, glazing etc) should be taken to be static ($C_r = 0$); this is why the pressure and surface load equations (Equations 4 and 6) exclude C_r .

Q7: How have the ground roughness categories changed?

- The 'ground roughness' categories 1 and 2 of CP3-V-2 are now merged into a single 'country' category.
- Ground roughness categories 3 and 4 of CP3-V-2 are now merged into a single 'town' category because they are distinguished only by the height of the upwind obstructions and that is now specifically allowed for by the parameter H_o .
- The new 'sea' category is only required to determine distance-to-sea, since the Standard does not apply to offshore structures.
- On Ordnance Survey 1:50,000 Landranger series maps, large areas of town are coloured pink, and smaller areas are marked small by black rectangles representing individual houses. On the *AA Big road atlas*^[1] and *Truckers atlas*^[2] (see *Design aids* at the end of this Digest), town is coloured brown and individual houses are not marked. It is generally safe to take the town boundary as the edge of these brown coloured areas. Areas of individual houses count as town where there is a sufficient number upwind of the site. (See Q8.)
- Country is everywhere else on land that does not qualify as town.

Q8: Why introduce the new 'obstruction height and distance' parameters and what do I do if I don't know their exact values?

- Obstruction height, H_o , is not new. CP3-V-2 assumed standard values in Appendix A, whether these were appropriate or not.
- The problem with a fixed standard value of H_o , such as $H_o = 10$ m for ground roughness 3 in CP3-V-2, is that:
 - ☐ if your building is 10 m high and surrounded by two-storey housing ($H_o = 6$ m), it sticks up above rooftop height and is more exposed than assumed; but
 - ☐ if your building is 10 m high and surrounded by 4-storey buildings ($H_o = 12$ m), it is more sheltered than assumed.
- If you do not know the exact value of H_o , estimate it from the typical storey height of 3 m given in the Note to §1.7.3.3. Take the average height of buildings upwind of the site over a distance of about 100 m upwind. In the standard method, a sector 45° either side of the normal to the building face should be considered. In the directional method, each 30° sector should be considered.
- Similarly, if you do not know the exact value of separation, you may take the value $X = 20$ m as typical of suburban and urban areas.
- If there are too few buildings upwind to find a reasonable average height (8% plan density, or 12 houses per hectare) or the buildings extend less than 100 m upwind, the criteria for town terrain is not met and the site should be treated as country terrain with $H_o = 0$. In this case, the site would be treated as ground roughness 2 under CP3-V-2.

Q9: What does the change to 'effective height' from 'height above ground' mean?

- In towns, BS 6399-2 and CP3-V-2 determine an effective height above ground by subtracting a displacement height from the actual height above ground. CP3-V-2, assumed fixed values of displacement height for each roughness category, so was able to tabulate the terrain-and-building factor in terms of actual height above ground. BS 6399-2 sets the displacement height appropriate to the actual height and spacing of upwind obstacles, so it tabulates the terrain-and-building factor in terms of effective height. The displacement height, H_d , is not used directly in the main body of the Standard, but is defined in Figure E.1.

Q10: What is the quickest way to work out the effective heights?

- You need to know the reference height, H_r , for each part of your building: this is always the top of the part (eg the height of the ridge for roofs, and the height of the eaves, gable or parapet for walls).
- Clause 1.7.3.3 is not simple to apply when you have many reference heights. In this case, the quickest way is to find the intermediate value of displacement height, H_d , defined in Annex E, as follows.
 - 1 Make a first estimate of displacement height from: $H_d = 1.2 H_o - 0.2 X$
 - 2 Check that this value of H_d does not exceed $0.8 H_o$: if $H_d > 0.8 H_o$, then $H_d = 0.8 H_o$
- Now find the effective height for each reference height, as follows.
 - 3 Estimate the effective height, H_e : $H_e = H_r - H_d$
 - 4 Check that this value is not less than $0.4 H_r$: if $H_e < 0.4 H_r$, then $H_e = 0.4 H_r$
- In practice it is found that buildings in towns that are lower than their upwind neighbours have an effective height $H_e = 0.4 H_r$. Typically this reduces structural loads to about 70% of the loads for an isolated building in a town (but see Q11).

Q11: What if the nearest neighbour is demolished in the future?

- Neither BS 6399-2 nor CP3-V-2 make any allowance for the direct shelter provided by individual neighbouring buildings. The rules for effective height account for the average effect of the upwind roughness described in Q8. Accordingly, the design wind speeds should not be affected by the demolition of any individual neighbouring building.
- The ground roughness rules of both BS 6399-2 and CP3-V-2 imply that urbanisation is irreversible in the long term, and that demolition of large areas will be followed by redevelopment. Where this is not the case, the wind loading on buildings around the edge of the demolition zone is likely to be increased. It will be prudent to reassess the stability of the vulnerable buildings or seek specialist advice. Similar advice is given in the Standard for tall buildings adjacent to low-rise buildings (§1.7.3.4).
- Note 1 to §1.7.2 allows you to treat permanent forest and woodland as town category. You need to be sure that the woodland will not be clear felled in the future. Obviously, this provision does not apply to commercial plantations.
- The one exception where it may be safe to account for the direct shelter of a nearby building and non-permanent woodland is in the design of temporary works or a building during construction. When the nearby building is at least as tall as the sheltered works, the shelter factor for freestanding walls in Figure 27 may be used for those parts of the works directly sheltered by the building.

Q12: What do I do if my building is in a town, but it borders an open space?

- BS 6399-2 allows for the open space by reducing the displacement height, H_d . For spaces larger than six times H_o , the effective height, H_e , is the actual height above ground. You should continue to use town roughness for sites bordering open spaces in towns (provided that the town extends > 2 km upwind in the standard method). CP3-V-2 required the use of the next most onerous category, Category 2, for buildings bordering open spaces in towns.

Q13: Why introduce distance-to-sea and distance-in-town?

- The wind speed does not change suddenly as it crosses the coast or enters a town. It slows down gradually, starting at ground level and working slowly upwards in height.
- CP3-V-2 stated that a fetch of 'a kilometre or more is necessary to establish a different roughness category' (Appendix A), meaning a minimum fetch of 1 km. In towns, CP3-V-2 allowed a lesser distance at heights below the average height of rooftops. This gave a step reduction to the loads on a 10 metre-high building of 42% for an inland town and 65% for a coastal town.
- Distance-to-sea, used in BS 6399-2, allows for the gradual decrease in wind speed from the coast, eliminating the large step change. At 2 km from the coast, BS 6399-2 matches CP3-V-2 ground roughness 1, and, at 20 km from the coast, it matches ground roughness 2. BS 6399-2 therefore gives reduced wind speeds at sites more than 20 km from the sea (ie for most of the UK).

- It was not found practicable to introduce the gradual change into towns in a simple way into the standard method: hence the step change at 2 km into the town. The standard method is conservative for all sites in towns except those exactly on, or at 2 km from, the town boundary. This results in loads on buildings in towns that are 14% higher on average than by the directional method.
- Clause 3.4.2 allows the standard method wind speed to be replaced with the worst wind speed within 45° either side of the normal to the building face found by the directional method. This process is greatly simplified by the BSI *Wind loading ready-reckoner*^[3] through a series of expanded tables of terrain-and-building factor, S_b . This is always of benefit for sites in towns, as described in Q16.

Q14: How do I measure distance-to-sea and distance-in-town?

- Choice 1 in Table A requires you to know the shortest distance-to-sea and the shortest distance-in-town in any direction.
- Choice 2 in Table A requires you to know the shortest distance-to-sea and the shortest distance-in-town in the range of direction 45° either side of each orthogonal case.
- Choice 3 in Table A requires you to know the average distance-to-sea and distance-in-town in each of twelve 30° -wide sectors of wind direction.
- The coastline is obvious on any map. Urban boundaries are also marked on Ordnance Survey 1:50,000 Landranger maps, sufficient to determine distances to the nearest 100 m which is all that is required.
- To determine the distance-to-sea and the distance-in-town, take the average distance 45° either side of the normal to the building face for the standard method, or each 30° sector of the directional method. This need not be determined any more finely than the steps of 100 m, 200 m, 500 m, 700 m, 1 km, 2 km etc as used in the *Wind loading ready-reckoner* tables.
- The most useful design aid for distance-to-sea is a UK road atlas^[1,2] which shows the 10 km National Grid squares.
 - ☐ For sites further than 20 km to the sea, simply count 10 km grid squares.
 - ☐ For sites between 2 km and 20 km to the sea estimate by 10ths of grid squares.
 - ☐ For sites closer than 2 km, use a larger scale map or site plan.
- It can be difficult to determine the effective distance-to-sea for sites close to estuaries and to the edges of towns with irregular boundaries. The simplest and safest advice is to use the closest distance to any water or open country, respectively, but this will often be very conservative. Figure A below gives better rules for estuaries and edges of towns.
- The distances marked by the arrows in Figure A should

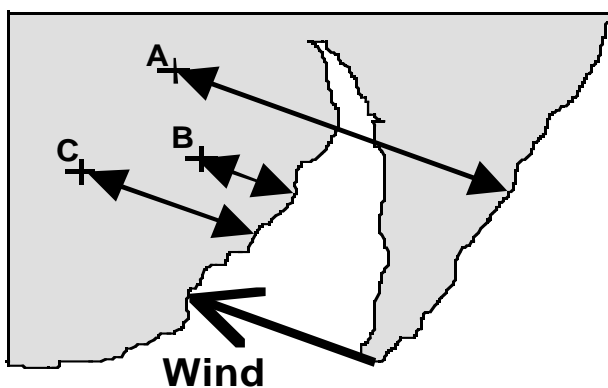


Figure A Distance-to-sea in estuaries and to edge of towns

be taken as the distance-to-sea or distance-in-town, noting the following.

- ☐ For site A, the distance to the estuary and the fetch of land upwind of the estuary are both greater than the distance across the estuary.
- ☐ For site B, the distance to the estuary is less than the distance across the estuary.
- ☐ For site C, the distance across the estuary is greater than the fetch of land upwind of the estuary.
- The above rules produce step changes in design wind speed while, in reality, there is a gradual change in wind speed with position along the estuary/town boundary. The full site exposure method, on which BS 6399-2 is based, is given in the BRE *Designer's guide to wind loading of building structures*, Part 1, and is implemented with the standard and directional methods of BS 6399-2 in the BRE computer program BREVe^[4].

Q15: What if my site is in country terrain but is downwind of a large town?

- Clearly, wind speeds will stay reduced for some distance downwind of a large town or city. Neither BS 6399-2 nor CP3-V-2 gives any allowance for this effect. The full site exposure method on which BS 6399-2 is based does give allowance for this effect. The method is given in the *Designer's guide to wind loading of building structures*, Part 1, and is implemented, with the standard and directional methods of BS 6399-2, in BREVe.

Q16: Which method should I use?

- You have a free choice of method, but it is expected that the simpler standard method will be used for manual calculations. The standard method is a simplification of the directional method and is conservative.
 - Choice 1 in Table A represents the single worst case irrespective of direction. This is directly equivalent to CP3-V-2 and is useful for initial back-of-envelope calculations. It is the most conservative choice, so, if you can justify the structure using this simple approach, no further calculation is necessary.
 - Choice 2 in Table A is directly equivalent to using CP3-V-2 with direction factors. This is the optimum balance between conservatism and complexity for use with manual calculations.
 - Choice 3 in Table A removes all conservatism from the wind speeds by using the worst wind speed for each case found by the directional method. This is over-complex for typical manual calculations, but if you are having difficulty justifying a particular component, you may wish to choose this approach to check a critical wind direction. With its 12 repeated calculations, this choice is suitable for spreadsheet based calculations.
- Q33 gives detailed guidance on each choice.
- The standard method is as similar as practicable to the method of CP3-V-2. It requires you to consider the same, two, three or four orthogonal load cases, depending on the symmetry of your building. Use of the direction factor, S_d , is optional.
- The directional method allows you to estimate the loads in 30° increments of wind direction using the direction factor together with directional pressure coefficients.
- On average the standard method gives dynamic pressures that are 14% higher than the directional method, but this conservatism varies from site to site in the range 0–30% depending on the exposure. The conservatism comes largely from the way the standard method treats sites in towns, with a step change of terrain-and-building factor, S_b , for sites further than 2 km inside the town. The directional method gives a gradually increasing allowance for town fetch.
- Clause 3.4 permits hybrid combinations of standard and directional methods. We will see later that using directional wind speeds with standard pressure coefficients (§3.4.2) recovers most of the conservatism of the standard method.
- For sites in towns, the simplest and most effective hybrid method is to replace the terrain-and-building factor, S_b , of the standard method in Table 4 (§2.2.3) with the values given by Equation 29 for the directional method (§3.2.3.2.3). This hybrid approach works with each of the choices of Table A, removing all the conservatism that occurs because of the step change at 2 km into the town.
- Several design aids are available to simplify the application of Equation 29, including:
 - the *Wind loading ready-reckoner*, from BSI, for manual calculations,
 - BREVe – *An aid to the use of BS 6399-2* for obtaining design wind speeds automatically from the National Grid reference, and
 - BREWS – *Software for BS 6399-2:1997*^[5].

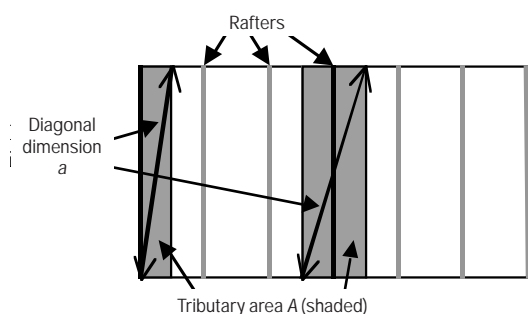


Figure B Tributary area and diagonal dimension for verge and centre rafters of a flat roof

Q17: CP3-V-2 gave force coefficients to determine overall loads. What do I do now?

- Both standard and directional methods determine the surface pressures on the building; therefore accumulate these to give surface loads and then overall loads. Separate force coefficients are no longer needed.

Q18: How do I get the loads on a structural element from the surface pressures?

- Structural loads are found by summing the surface pressure over the 'tributary area' (see Figure B) of the external envelope with an allowance for size effect.

- The tributary area is the area of the external envelope that attracts load to the structural element. For a purlin or sheeting rail this is simply the area of cladding that it supports. For the longitudinal wind-bracing elements of a portal frame it is the area of the gable walls, since this is the area of external envelope that attracts the longitudinal load the bracing must resist. For the frictional drag component (§2.1.3.8) it is the area swept by the wind, A_s .
- The tributary area for a verge and a centre rafter of a flat roof is shown in Figure B. In this case the tributary area extends for the length of the rafter with a width that extends halfway to the adjacent rafter(s).

Q19: What is the new 'size effect factor' in the standard method?

- In CP3-V-2 the 'building size' was part of the 'ground roughness, building size and height above ground factor', S_2 : Classes A, B and C. In the standard method this is separated out as the size effect factor, C_a , but in the directional method it remains part of the terrain-and-building factor, S_b .
- The maximum surface pressure at a point on a building occurs when a range of gusts, from large to very small, act together. Over a surface, the smallest gusts do not act together, reducing the average maximum pressure.

Q20: How do I determine the diagonal dimension?

- Where there is no significant load-sharing across the structure, the area that defines the diagonal dimension, a , for the size effect factor, C_a , is the tributary area (see Q18). When the tributary area is not a rectangle, the greatest distance between corners should be taken as the diagonal dimension.
- Where there is significant load-sharing, the area that defines the diagonal dimension, a , will be larger than the tributary area. This means that part of the localised gust loads on the surface is shed onto adjacent elements that are not simultaneously loaded by the gusting. This larger area must be defined from consideration of the structural form and the relative stiffness of components and joints.
- The size effect factor reduces by only about 5% when the diagonal dimension is doubled. The diagonal of the tributary area is always conservative and should be used unless the degree of load sharing is large enough to justify the effort of assessment.
- The tributary area for a verge and a centre rafter of a flat roof is shown in Figure B.
- For overall horizontal forces, the horizontal projection of the structure in the direction of the wind may be used to determine a . This is shown in Figure C(a) and (b).
- For the lateral loads on a portal frame with the direction of wind parallel to the frames, a rectangle of height equal to the height above ground of the ridge and width equal to the spacing of frames should be considered. This is shown in Figure C(c).

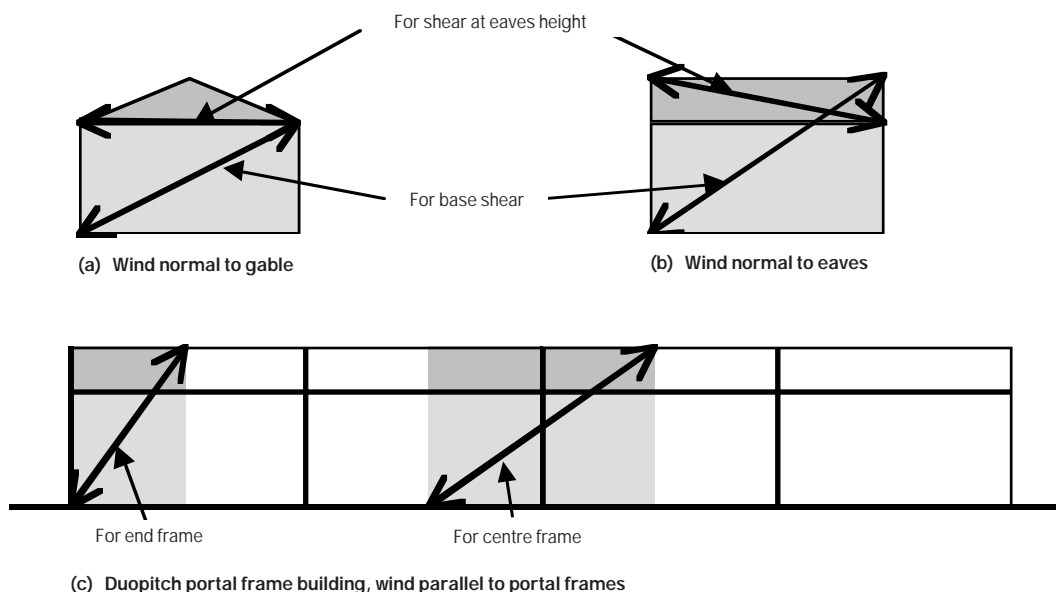


Figure C Diagonal dimension for horizontal forces

Q21: What is the most efficient way of using the size effect factor?

- The size effect factor, C_a , has been separated out in the standard method to reduce the number of manual calculations. The load on any element can be calculated as follows.
 - 1 Determine the distribution of external pressures, p_e , over the surface of the building using a value of $C_a = 1$. (We shall call this the **unfactored** external pressure in the worked examples of Parts 2 and 3 of this Digest.)
 - 2 Determine the internal pressure, p_i , using a value of $C_a = 1$. (We shall call this the **unfactored** internal pressure in the worked examples of Parts 2 and 3.)
 - 3 Determine the size effect factor, C_a , for the external pressures on each building part or component.
 - 4 Determine the size effect factor, C_a , for the internal pressure from the relevant volume of the building.
 - 5 Apply the appropriate size effect to each part or component to find the surface load using $P = (p_e C_a - p_i C_a) \times A$.
 - 6 Where the relevant load is accumulated over a number of parts or components (eg roof and walls – see Figure C), sum the unfactored internal and external pressures from steps 1 and 2 over each area and apply the size effect factors from steps 3 and 4 to the summed loads using:

$$P = \sum(p_e A) \times C_a - \sum(p_i A) \times C_a$$
- Note that the internal pressure, p_i , is not required for overall horizontal loads since it cancels out on the inside faces of front and rear walls.

Q22: Why is the factor 0.85 used in Equations 7, 22 and 23 to obtain overall loads?

- The size effect factor works only over a single face. When a wind gust produces the maximum load on the front face of a building, the load on the rear face will not also be at its maximum. It is more likely to be near the mean value.
- The factor 0.85 in Equations 7, 22 and 23 adjusts the maximum face loads for this non-simultaneous action and applies only when front and rear faces act together to give the overall horizontal load.
- Note also that these are the only equations that use the dynamic augmentation factor, C_r . (See Q6.)

Q23: If I take D as the smaller of W or L in §2.1.3.6 for overall loads, I can never take advantage of the reduced pressure coefficients for $D/H \geq 4$. Is this correct?

- In §2.1.3.6 the provision ‘but taking the in-wind depth of the building, D , as the smaller of width W or length L ’ is unnecessarily onerous. A recommendation to omit this has been made to the BSI Committee.

Q24: Do I always have to apply the rule of asymmetric loads in §2.1.3.7?

- Some symmetrical structures easily able resist the symmetric loading patterns provided by the standard method could be sensitive to even small asymmetry of loads.
- A simple example is a signboard mounted on a central post. BS 6399-2 would predict no torque on the post if Figure 28 did not indicate that the centre of load ranges by $B/4$ either side of the centre line. The standard method also predicts no net torque on a rectangular-plan building.
- In the standard method, allowance for asymmetric loads on conventional structures is made through §2.1.3.7 which states that the load on each wall or roof pitch should be reduced, in turn, to 60% of the design value. If this action increases the load in any member or connection, the member should be designed for this increased load.
- Clause 2.1.3.7 states ‘the influence function for a structural component having a region of negative

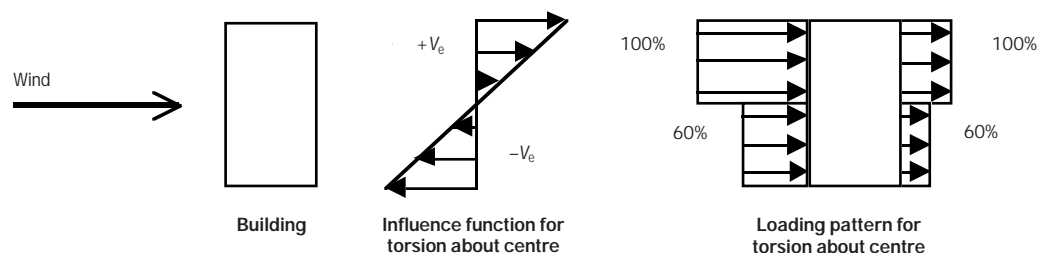


Figure D Influence function for torsion of core and loading pattern for torsion of core required by § 2.1.3.7

value, 100% of the design loads to areas contributing to the positive regions and 60% of the design loads to areas contributing to the negative regions should be applied'. This is illustrated for the case of torsion on the central core of a rectangular tower in Figure D opposite.

- The above procedures are analogous to assigning different load factors to adverse loads and to beneficial loads to arrive at the most critical combination of loads in structural design.
- In the directional method, the zones of pressure coefficient are designed to predict the asymmetric loads, even when the wind is exactly normal to a face, so this rule is not needed.

Q25: Why has the wind speed map changed so much?

- The wind speeds on the map are all much lower because the map now gives mean hourly wind speeds. These are converted into gust speeds later by the terrain-and-building factor, S_b . There are several reasons for this change, including:
 - mean wind speeds that are required for dynamic design methods. BS 6399-2 is now better able to provide wind speed data to dependent Standards that use dynamic methods.
 - hills and escarpments that accelerate only the mean wind speed. (See Q28.)
- Because distance-to-sea is specifically addressed, the effect of the strongest south west to west wind directions has been removed from the basic wind speed map. This means that basic wind speeds along west and south-facing coasts are lower than their equivalents in CP3-V-2. This is not the case for sites along east and north-facing coasts because the strongest wind direction is then offshore.
- Map wind speeds in Scotland have reduced due to longer and better data records. Those in East Anglia have increased slightly.
- The effect of site altitude has been removed from the map and presented as a separate altitude factor, S_a . (See Q27.)

Q26: What if a client wants me to use BS 6399-2 for an overseas site and gives me a gust wind speed?

- The Foreword of BS 6399-2 makes it clear that, like CP3-V-2, BS 6399-2 is intended for use only for sites in the UK. Nevertheless, many countries accept designs assessed to the current UK Standard, so the relevant procedure is given. This is explained in more detail below.
 - Only the basic wind speed and climate factors are unique to the UK, so you need to obtain the relevant site wind speed, V_s , for the overseas site. This is the hourly-mean wind speed at 10 m above open level ground appropriate to the geographical location of the site. This is a standard meteorological parameter, so should be available from the local meteorological authority.
 - If you are given a gust wind speed compatible with CP3-V-2, you should treat it as follows.
 - Take the gust speed to be the effective wind speed, V_e , for $H_t = 10$ m in country terrain, in the standard method.
 - Determine V_s by dividing the gust speed by the terrain-and-building factor for the reference terrain in Table 4.
 - Determine the appropriate value of S_b for the relevant effective height and site location, from Table 4 and multiply by V_s to obtain V_e .
- (Note: The effect of distance-to-sea is assumed to be included in the reference gust wind speed, so reference and site values of S_b should be taken for the same distance-to-sea.)
- Example: determine standard method effective wind speed for effective height of 20 m in town terrain more than 100 km inland, given a basic gust speed of 44 m/s for the site.
 - Equivalent site wind speed $V_s = 44 / 1.62 = 27.2$ m/s. (For $H_e = 10$ m, $S_b = 1.62$ in country.)
 - Terrain-and-building factor $S_b = 1.77$ for $H_e = 20$ m in town.
 - Effective wind speed $V_e = 27.2 \times 1.77 = 48.1$ m/s.

Q27: What is the purpose of the altitude factor?

- Altitude was previously included in the basic wind speed map, but the scale of the map is too small to distinguish high ground properly.
- The new altitude factor reduces the need to apply the complicated topography rules.
- Altitude factor in the standard method incorporates both altitude and topography effects, using the same procedure for topography as CP3-V-2.

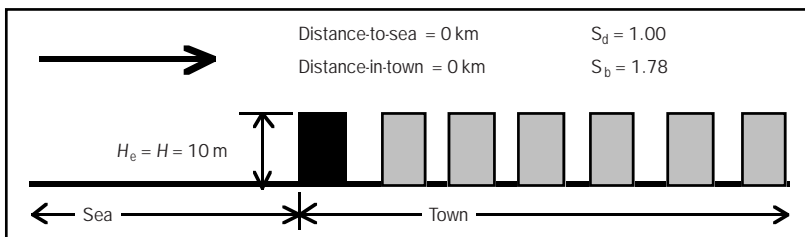
Q28: How has the topography method changed?

- The basis of the topography method is unchanged from the 1986 amendments to CP3-V-2.
- The criteria for significant topography are much simpler in BS 6399-2 than in CP3-V-2 and apply less often, as defined in Figure 7. It should be obvious when a site is in the upper half of a hill or close to the crest of an escarpment. Figure 7 makes it clear that the average upwind slope of the hill or escarpment must be greater than 0.05 (1 in 20) before the feature is significant.

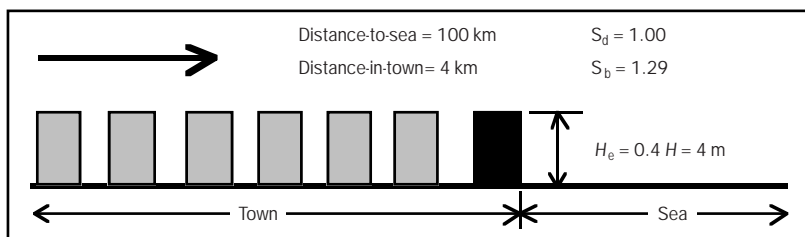
Q29: Must I use the direction factors?

- The direction factor, S_d , is effectively optional, as in CP3-V-2 (S_4), since you may use the maximum value $S_d = 1.00$ for all wind directions (§2.2.2.3). But the penalty for this simplification is increased conservatism.
- Using the directional factor, S_d in BS 6399-2 and S_4 in CP3-V-2, leads to values of dynamic pressure for winds from the south east ($S_d = 0.73$) that are only 53% of the values for winds from the south west ($S_d = 1.00$). Because the building must withstand the most onerous wind loads in all four orthogonal cases, it is often not possible to take full advantage of this reduction.
- Direction factor plays a key part in reducing conservatism through the use of §3.4.2. This occurs because the most onerous combination of the other parameters – distance-to-sea, distance-in-town, slope of topography, obstruction heights and spacing etc – may not correspond to the strongest wind direction. (See Q31.)
- Close to east and north-facing coasts, it is always advantageous to account for wind direction at least in terms of offshore and onshore winds. The largest direction factor will usually be $S_d = 1.0$ for offshore winds (large distance-to-sea, ≈ 100 km). For onshore winds, take the largest direction factor in the range (typically $S_d = 0.80$ for $\phi = 150^\circ$, or $S_d = 0.74$ for $\phi = 90^\circ$) in combination with the closest distance-to-sea.
- Similarly, close to the eastern and northern boundaries of towns it is also of advantage to account for 'on-town' and 'off-town' winds. When distance-to-sea and distance-in-town are both small (ie near the seafront of coastal towns), these two effects combine as illustrated by Figure E below and Table B opposite.

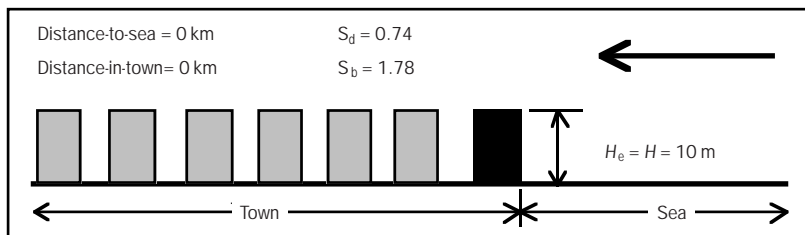
- Using the standard method without accounting for direction (option 1 in Table A) penalises sites close to east and north-facing coasts because the effect of wind direction through the direction factor, S_d , is stronger than the effect of distance-to-sea in the terrain-and-building factor, S_b . In the absence of significant topography, the strongest wind will always occur in the range $\phi = 210^\circ$ through $\phi = 300^\circ$, so it is safe to use the closest distance-to-sea in this range with $S_d = 1$.



(a) West coast town, onshore wind



(b) East coast town, offshore wind



(c) East coast town, onshore wind

Figure E Effect of onshore and offshore winds on coastal sites

Table B Comparison of onshore and offshore winds on coastal sites with same basic wind speed

Parameter	West coast, onshore	East coast, offshore	East coast, onshore
Basic wind speed, $V_b =$	25 m/s	25 m/s	25 m/s
Direction factor, $S_d =$	1.00	1.00	0.74
Table 4, terrain-and-building factor, $S_b =$	1.78	1.29	1.78
Effective wind speed, $V_e =$	44.5 m/s	32.25 m/s	32.93 m/s
Design dynamic pressure, $q_s =$	1214 Pa	638 Pa	665 Pa

Q30: Has the design risk changed?

- The standard value of design risk remains the same: an annual risk of 0.02 is the same as the once-in-50-year risk.
- The way that the design risk is described has changed from a high risk (63%) in a long period (50 years) to the equivalent small annual risk (2%). This is to emphasise that the 50-year period in CP3-V-2 does not represent a building's lifetime. The annual risk describes the risk to the public for every year that the building is operational.
- When the partial factors on load are included, both CP3-V-2 and BS 6399-2 aim to achieve an annual risk less than 0.0005 (1 in 2,000) of damage and less than 0.0001 (1 in 10,000) of fatality.

Q31: May I use the seasonal and probability factors together?

- The probability factor, S_p , can be used to change the level of risk from the standard design annual risk $Q = 0.02$ (50 years average recurrence interval). However, partial factors, γ_f , for permanent structures in BS design codes, assume the value $S_p = 1.00$ is used.
- For buildings under construction or temporary works, it is appropriate to use the seasonal factor, S_s , with $S_p = 1.00$ which maintains the standard design risk in the stated period.
- However, at the discretion of the designer, seasonal and probability factors may be used together to obtain a non-standard risk in any sub-annual period. In this case the designer should carry out an assessment of the appropriate non-standard risk.
- The equation for probability factor is given in Annex D of BS 6399-2 together with some example values.
- These example values have led to some misunderstandings. Note 2 of Annex D shows that reducing the partial factor for loads from $\gamma_f = 1.4$ at the ultimate limit to $\gamma_f = 1.0$ at the service limit is equivalent to reducing the probability factor from $S_p = 1.00$ to $S_p = 0.845$. The quoted value $S_p = 0.845$ should be treated as an example, **not a design recommendation**.
- For design at the serviceability limit, use $\gamma_f = 1.0$ together with a probability factor that expresses the appropriate design risk of exceeding the serviceability limit. (See Q46.)

Q32: How does the terrain-and-building factor differ from S_2 ?

- The terrain-and-building factor, S_b , now includes the change of the mean speed to gust speed. This is $1.78 \times S_2$ factor in CP3-V-2 for the same terrain roughness at 10 m above ground.
- The datum calibration point is between CP3-V-2 ground roughness 2 and BS 6399-2 'country' at 20 km to the sea. Therefore wind speeds are reduced for most of the UK that lies further than 20 km to the sea.
- The comparison between CP3-V-2 and BS 6399-2 is given in Table C. Note that the values are very similar, except that BS 6399-2 is slightly more onerous for taller buildings ($H = 30$ m) and for low-rise buildings in 'cities' ($H = 10$ m in Category 4).

Note A

BS 6399-2 does not permit the use of 2 m-high permanent obstructions in country terrain.

Table C CP3-V-2 standard ground roughness assumptions recast in terms of BS 6399-2

Category	Terrain description	H (m)	H_e (m)	$S_2 \times 1.78$	S_b
1	Flat open country, 2 km to the sea	10	10	1.78	1.78
		30	30	1.94	1.96
2	Typical farmland, 20 km to the sea, 2 m high obstructions (see Note A)	10	8	1.66	1.66
		30	28	1.90	1.94
3	2 km inside town, 12 m high buildings, 20 km to the sea	10	4	1.39	1.37
		30	20	1.80	1.87
4	2 km inside town, 30 m high buildings, 20 km from the sea	10	4	1.19	1.28
		30	12	1.60	1.63

Q33: Can you demonstrate the options for finding the effective dynamic pressure for the orthogonal load cases used in the standard method?

- The options range from speed and simplicity with conservatism to more detailed calculations without conservatism.

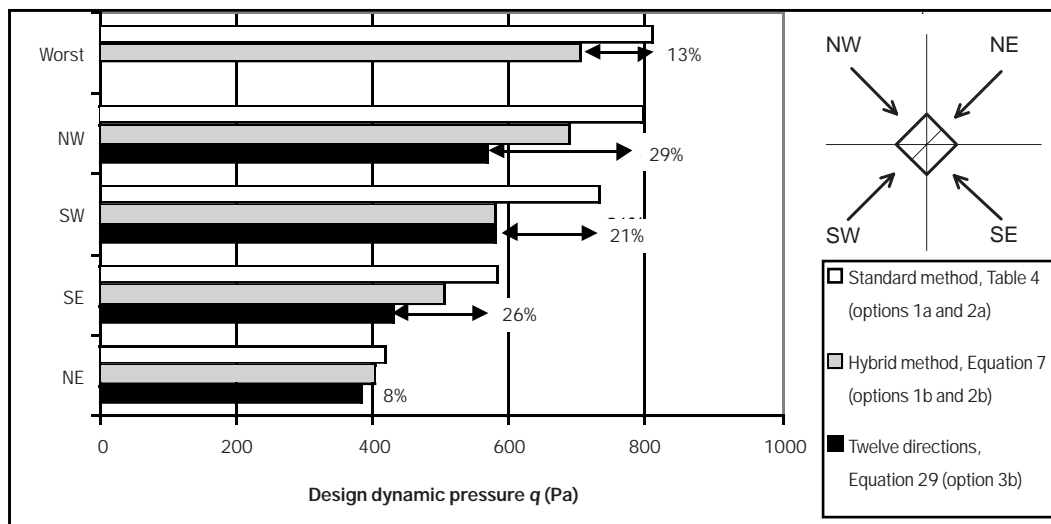
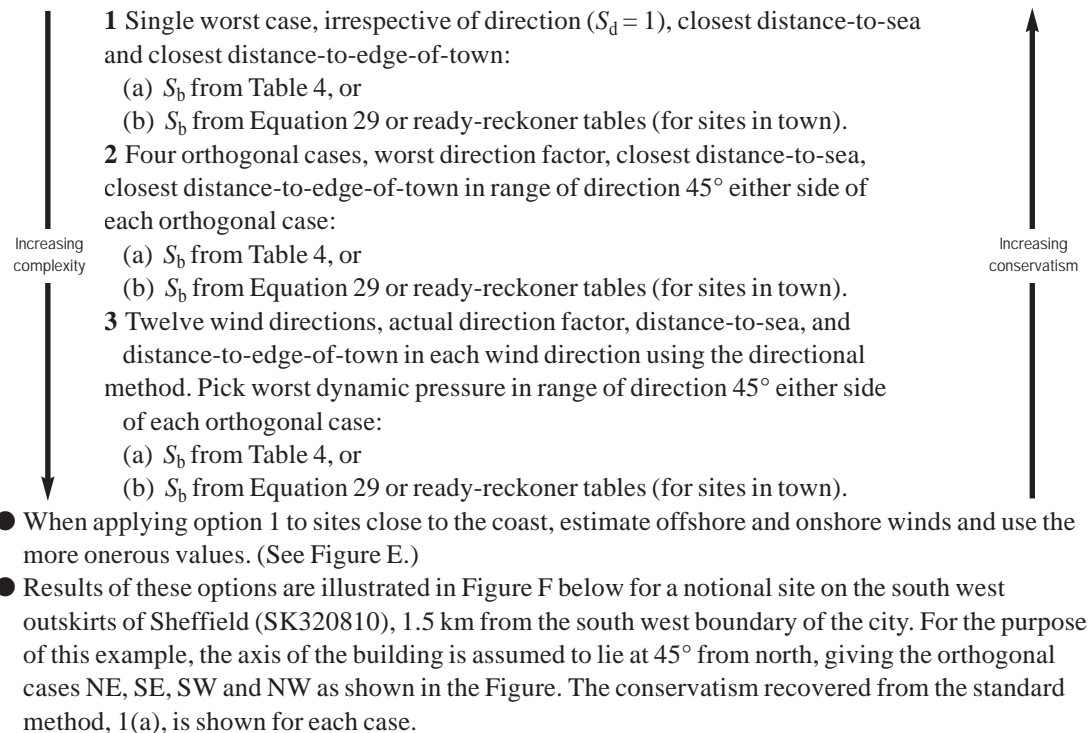


Figure F Effective dynamic pressures for south west Sheffield site by various options

- Inside towns you should expect to remove between 0% and 30% (but on average about 14%) conservatism on dynamic pressure by using Option 3(b), instead of the simple worst case, irrespective of direction, Option 1(a).
- When a site is on the town boundary, the change in effective height between $H_e = H_r$ for on-town and $H_e = 0.4 H_r$ for off-town exposures gives an additional 30% difference in loading as described in Q10.

Q34: Why has the 'division by parts rule' changed?

- The aerodynamics that led to the division by parts rule works only for the positive pressures on the middle region of the windward face of slender buildings, as defined in Figure 11.
- CP3-V-2 allowed the rule to be applied beyond the limits of its applicability. Codes for other European countries make no allowance for this effect.

- The suctions on side and rear faces are almost uniform with height, and depend on the dynamic pressure at the top of the building. The small variation that does occur acts in the opposite sense to this rule, with higher suctions towards the base of the building.
- The rule should not be applied to suction loads and the rules for division given in §2.2.3.2 should be observed.

Q35: Is there much advantage to using the directional pressure coefficients?

- The tables of pressure coefficients in the standard method have been built using the most onerous directional method values for each zone in the 45° range of wind direction appropriate for the load case. This implies some degree of conservatism in that the most onerous loads are likely to occur in different wind directions, but this is much smaller than the average 14% conservatism between standard and directional dynamic pressures.
- In general, the standard method pressure coefficients should be used for manual calculations.
- But when the loads are critical to the design and may result in the selection of a larger member size, it may be of benefit to check the critical loads using the pressure coefficients of the directional method.
- The hybrid approach, using wind speeds obtained using Equation 29 of the directional method with standard method pressure coefficients for each orthogonal case (Case 2(b) in Q33), is recommended as the best all-round option.

Q36: Are the local pressure coefficients higher?

- Values of pressure coefficients have changed as a result of better knowledge gained over the last 30 years.
- Original CP3-V-2 pressure coefficients were derived from mean measurements in smooth-flow wind tunnels and the local values were added from BRE measurements on houses. The new pressure coefficients are based on full scale measurements and wind tunnel tests where the wind speed and turbulence have been properly represented.
- The new pressure coefficients give higher suctions near the edges of buildings, but lower values elsewhere, so that structural loads tend to decrease but local cladding loads seem to increase.
- However, you should also consider the changes to the standard range of internal pressure coefficients and the change in size of the zones.
- The positive internal pressure coefficient of $C_{pi} = +0.2$ is now an exception instead of the rule.
- Typically the largest net suction coefficient for walls is $C_p = C_{pe} - C_{pi} = -1.0$ (but -1.3 at maximum funnelling). CP3-V-2 gave the range $-1.4 \leq C_p \leq -1.0$.
- The maximum suction on flat roofs, $C_{pe} = -2.0$, is unchanged, but its zone is generally much smaller in BS 6399-2 than in CP3-V-2.
- Calibrations studies show, on average, that BS 6399-2 reduces net cladding pressures and suctions.

Q37: Why do the sizes of pressure coefficient zones change with the building proportions?

- This is also a result of improved knowledge. The fixed proportions in CP3-V-2 relate to typical domestic housing.
- The size of the high suction zones at the edges of roofs and side walls depends on how much the wind has to diverge from its path to pass around the building, as illustrated in Figure G.
- Zone scaling therefore depends on the scaling length b , which is always the smaller of B or $2H$, from:

$$b = \begin{cases} B & (B \leq 2H) \\ 2H & (B > 2H) \end{cases}$$

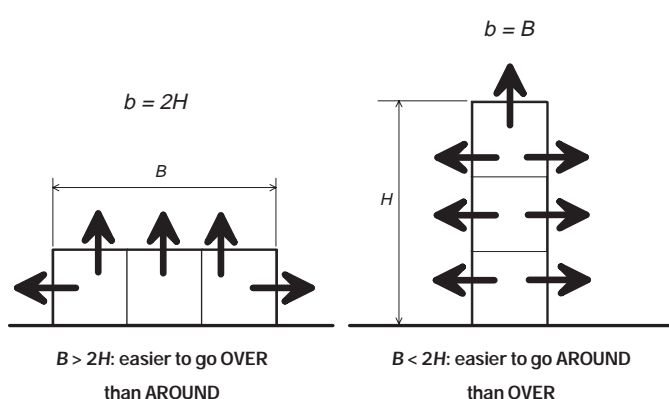


Figure G Principle of the rules for scaling length b

- Changing the zone sizes according to the frontal proportions of the building requires fewer and smaller pressure coefficient tables, and gives a more representative result. For example, the table for walls (Table 5 in BS 6399-2) is now much simpler than Table 7 in CP3-V-2 because it does not need different values for each range of proportion (h/w and l/w).
- For long-span buildings, the highly loaded roof zones reduce in size, greatly reducing roof loads in comparison with CP3-V-2.

Q38: What do I do when a cladding panel or structural element spans more than one zone?

- A cladding panel attracts load from the area of the external envelope that it occupies: the tributary area (see Q18). Where that area encompasses more than one zone of pressure coefficient, BS 6399-2 predicts a step change in loading across the panel.
- This may not be convenient for design when the panel is rated for a uniform load (eg in tables of permissible pressure for glazing). In this event, the pressure averaged over the area of the panel may be used. However, the step change in pressure across the panel indicates that the fixings may need to be stronger along the edge of the zone of higher pressure.
- Where an element of the structure lies across a number of pressure coefficient zones (eg a rafter), the end fixing loads are better determined from the moments produced by the zone loads. Either the zone loading or the averaged load could be used to design the element. This choice is a matter of engineering judgement.

Q39: Will zone sizes change if I add an extension to a building?

- When there are significant alterations or extensions, care should be taken to determine if higher wind loads are likely to occur on the existing parts of the building.
- Depending on whether the crosswind breadth, B , or height, H , determines the scaling length, b , increasing either B or H by adding an extension may give larger pressure coefficient zones on the remainder of the building.

Q40: Why has funnelling been introduced?

- The potential of funnelling to increase suctions on side walls has been suspected for a long time from the amount of failures that occur to the gable walls of houses, but reliable values of the coefficients have only recently been obtained.
- Previously, the conservatism inherent in CP3-V-2 has partly compensated for the effects of funnelling. The potential for large reductions in effective dynamic pressures at typical inland sites, now offered by BS 6399-2, meant that funnelling can become critical.
- Funnelling begins to occur when the gap between buildings becomes smaller than the scaling length, b , and reaches a maximum when the gap between buildings is $b/2$. At smaller gaps funnelling decreases, ending at a gap of $b/4$, when the wind finds it easier to go around and over both buildings than to force its way through the gap.

Q41: Does funnelling affect an existing building when a new building is constructed?

- The simple answer is yes. In the same way that tall buildings increase the loads on nearby low-rise buildings (§1.7.3.4), if funnelling is significant for a new building it will also be significant for the existing neighbouring building.
- Like the case of demolition in Q11, it will be prudent to reassess the stability of the vulnerable buildings or seek specialist advice.

Q42: How do I find the horizontal and vertical loads on curved surfaces?

- Table 7 gives pressure coefficients for walls of circular-plan buildings. You can use these for any circular segments of walls on the front or side faces of a building. A curved segment on the rear face of a building will have the same pressures as the rest of the rear face.
- You may find the horizontal loads on curved walls by integrating the pressure around the curved surface. Take the overall loads on a circular plan building to be:

$$P = 0.5 q_s D H (1 + C_r)$$
 in place of Equation 7, where the value 0.5 represents the drag coefficient of a supercritical cylinder and is equivalent to integrating the pressure coefficients of Table 7 around the circumference.
- BS 6399-2 does not give pressure coefficients for curved barrel vault roofs or domes. Values for these roof forms are given in Reference 6 of BS 6399-2.
- Pressure coefficients for barrel vault roofs can be estimated from Table 10 for duopitch roofs, taking the local slope at the eaves as pitch angle for zones A and B, and the average slope from eaves to crest as the pitch angle for the remainder of the roof.

Q43: How have the internal pressure rules changed?

- In the standard method, the most important change to the internal pressure coefficient values for enclosed buildings (Table 16) is that the positive value $C_{pi} = +0.2$ is now less likely to be a critical design case. The positive value can only occur when the side walls are impermeable and the front face is permeable. This reduces the net suction on side walls for the majority of buildings.
- The definitions of permeable and impermeable in Table 16 are relative and may be distinguished by a factor of two. If a first surface is more than twice as permeable as a second surface, the first is permeable and the second is impermeable. 'Face' in Table 16 means all external faces including roofs as well as walls.
- In general, faces with opening windows and doors or ventilators will be permeable and faces without openings (masonry, profiled metal cladding etc.) will be impermeable.
- The internal pressure coefficient for completely clad enclosed warehouse-type buildings, without opening windows, may be taken as $C_{pi} = -0.3$.
- The time it takes to change the internal pressure of enclosed buildings is now accounted for by using an equivalent diagonal dimension, a , determined from the building volume.
- Guidance is now given as to what constitutes a 'dominant opening', but this requires information on the porosity of the walls.
- Internal pressure coefficients are given for open-sided buildings in Table 18 and open topped cylinders (eg tanks) in Table 19.

Q44: Where do I get information on the porosity of buildings?

- There is little information available on absolute values of porosity, and such data that exist reflect national differences in the airtightness of construction. The UK tends to have the least tight construction and Sweden has the tightest construction. However, absolute values are required to compare with areas of openings to determine if the openings are dominant. The values in Table D may be taken as typical.

Table D Typical porosity of construction

Form of construction	Porosity
Office curtain walling	Open area / total area = 3.5×10^{-4}
Office internal partition walling	Open area / total area = 7×10^{-4}
Typical housing in UK	Open area / total area = 10.5×10^{-4}
Energy efficient housing	Open area / total area = 4×10^{-4}
Single leaf door	Calculate using gap width = 1.5 mm when closed

Q45: Do I always have to apply §2.6.1.2 when my building is subdivided into rooms?

- For buildings subdivided into rooms, the provisions of §2.6.1.1 should be taken as typical.
- Clause 2.6.1.2 covers the worst case that can occur when the internal partitions are less than three times more porous than the external walls. This is exceptional but will occur for party walls between terraced houses or industrial units.
- Damage does occasionally occur to internal partitions in strong winds. You should consider using §2.6.1.2 as a serviceability limit state (with $\gamma_f = 1.0$).

Q46: What design risk should I use to assess dominant openings as a serviceability limit state?

- Where a door or other opening that is normally closed would be dominant if open, it is usual to design for the ultimate load case with the door closed using the internal pressures for enclosed buildings.
- However, the designer should also check the case of the door open as a serviceability limit with an appropriate probability factor, S_p . The serviceability limit may control the design, in some cases.
- To be compatible with previous practice, a value of $S_p = 0.80$ is recommended for this serviceability check. This corresponds to a return period of two years: the minimum permitted by CP3-V-2 for 'temporary structures'. In practice this would require that the doors remain closed during winter storms forecast by the UK Meteorological Office as likely to cause structural damage.
- For buildings with permanent dominant openings and buildings that must remain operational in storms (eg housing emergency services), the appropriate value of S_p remains unity.

Q47: Why have the force coefficients on lattice frames and towers been removed?

- Lattice towers and masts now have a separate Standard, BS 8100, and this gives much more extensive and accurate loading coefficient values than CP3-V-2. It was not considered appropriate to duplicate these data in BS 6399-2. BS 8100 is essentially a dynamic Standard. For static lattice towers, it would be appropriate to adopt the BS 8100 loading coefficients into the BS 6399-2 method. Take care to use the BS 8100 definitions of face area when applying the BS 8100 coefficients.
- The pressure coefficients for elements given in Section 2.7 of BS 6399-2 are sufficient to give conservative estimates of wind loads on all unclad frames associated with buildings.
- Better estimates of wind loads on unclad building frames are given in References 6 and 7 of BS 6399-2.

Acknowledgements

The preparation of the three parts of this Digest has been funded by the Construction Directorate of the Department of the Environment, Transport and the Regions.

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British Standards Institution

BS 0 A standard for standards

BS 4076:1989 Specification for steel chimneys

BS 4485-4:1996 Water cooling towers. Code of practice for structural design and construction

BS 5502 Buildings and structures for agriculture

BS 5534-2:1986 Code of practice for slating and tiling. Design charts for fixing roof slating and tiling against wind uplift

BS 6262:1982 Code of practice for glazing for buildings (A new *British Standard* BS 6262-3 is being prepared and should be published in 1999)

BS 6399-2:1997 Loading for buildings. Code of practice for wind loads

CP3-V-2:1972 Loading. Wind loads

BS 8103-2:1996 Structural design of low-rise buildings. Code of practice for masonry walls for housing

BS 8103-3:1996 Structural design of low-rise buildings. Code of practice for timber floors and roofs for housing

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